vaporizer number one section. The long term durability and overall effectiveness of the partial boiling vaporizer is demonstrated in Table 4, which shows the unchanged vaporizer (i.e. heat exchanger) effectiveness before and after two types of cycles. Heat exchanger effectiveness is defined previously.

TABLE 4

Low Pressure Vaporizer number two, Comparison of Vaporizer Effectiveness before and after cycles

| Type of Cycle | Duration (hours) | HEx Effectiveness before cycle | HEx Effectiveness after cycle |
|---|---|---|---|
| Loss of air flow | 17 | 0.57 | 0.57 |
| Loss of system power | 3 | 0.54 | 0.54 |

Post Operation Analysis:

[0271] The water-side header and footer were removed and found to have scale deposits. The scale deposits also extended through the microchannel regions. Upon visual inspection with boroscope, the scale was located evenly throughout the microchannel region. Each channel appeared to have an equal amount of scale in similar areas. This indicates that flow was uniform through the microchannel region. Using SEM and EDS, the scale deposits were evaluated and found to contain a significant amount of Ca, Si, Mg and O, which are consistent with those elements in hard water scales. Additionally, the scale was found to contain matches to calcite, gypsum and other typical minerals found in hard water scale. Thus the probable conclusion is that the device suffered from typical hard water scaling. A calculation of shear stress and shear rate was done for these examples.

[0272] Geometry for low P vaporizer: 1×0.02×1, total 12 channels

[0273] Fluid: water

[0274] Flow rate: 20 (Vap. #2) and 28.4 (vap. #1) ml/min (total flowrate for device)

[0275] Calculation of Shear Rate and Stress.

| | LP Vap. #1 | LP Vap. #2 |
|---|---|---|
| Shear rate: Max. (1/s) | 35.3 | 24.8 |
| Min. (1/s) | 5.65 | 4.0 |
| Avg.(1/s) | 34.8 | 24.5 |
| Shear stress: Max. (Pa) | 0.036 | 0.026 |
| Min. (Pa) | 0.0029 | 0.002 |
| Avg.(Pa) | 0.035 | 0.025 |

[0276] As noted in this example, the shear stress in the microchannel during the partial boiling operation was two orders of magnitude lower than the shear stress for the example described in example 3 with the long microchannels on the order of 24 inches.

[0277] Overall Performance Summary:

TABLE 6

Overall Partial Vaporizer Performance Summary

| Total Dissolved Solids (ppm) | Percent Boiling (%) | Operating Pressure (psig) | Time on Stream (hrs) | Onset of fouling (hrs) |
|---|---|---|---|---|
| ~1 | ~31 | 2.9 | 9125 | NA |
| 12–15 | initially 85 | 0.7 | 2041 | ~478 |
| ~1 | 40–50 | 294 | 6239 | NA |

## EXAMPLE 7

### Temperature Profile Advantage—Modeling Comparison

[0278] The high heat transfer characteristics of microchannels enables partial boiling while maintaining low heat transfer wall temperature. The small temperature difference between the wall and the fluid in the micro-channels prefers nucleate boiling regime to film boiling regime and hence provide more stable boiling in the channels. A mathematical model was developed for partial boiling and the modeling results for micro-channel and large dimension channels were compared to demonstrate micro-channel advantage.

[0279] The geometry of the vaporizer modeled is shown in **FIG. 29**. The heat for vaporization is provided by cartridge heaters. The fluid used for vaporization is methanol. The methanol enters the channel at room temperature (25° C.) and exit the channel at ambient pressure. The heat from the cartridge heater was adjusted to obtain 75% vapor quality (mass basis).

[0280] The width of the flow channel was 1.0while the height of the channels was varied from micro-dimension to macro-dimension. The length of the channel was 4.0. The diameter of the cartridge heater was 0.375and length of the heater was same as the length of the channel. The heater provided uniform surface heat flux. A construction material for the vaporizer was stainless steel. The metal wall between the heater and the channel was 0.02". A 0.25" perimeter was assumed surrounding the channel and the heater. Two cases were considered by varying the channel gap:

[0281] Case 1: Channel gap=0.050"

[0282] Case 2: Channel gap=0.375"

[0283] For both the cases, methanol flow rate of 3.7 ml/min was used. The heater setting was also kept constant. No heat losses to the surrounding were assumed in the model. Also at any cross-section perpendicular to the flow direction, the variations in metal wall temperature were ignored. Heat transfer coefficient for pure liquid phase was calculated from fully developed Nusselt number in rectangular channels.

$$h_{liq} = \frac{Nu \times k}{D_h} \tag{17}$$